TERMINOLOGY OF THE THEORY OF RELAY DEVICES

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INTRODUCTION

The first terminology list in the area of the theory of relay devices was prepared and published in the USSR in 1950 (ref. 1) and in a somewhat revised form was published in the Collection of Recommended Terms in 1953 (ref. 2). This list was developed with application to the relay switching technology which was most widely used at that time.

During the succeeding ten years both the theory itself and the technology of the relay devices have received significant development. Along with the contact-type relay elements, there has been widespread introduction of the contactless elements. There has been considerable development of the methods of synthesis by means of the so-called "abstract" stage in which the relay device is considered, independently of the type of relay elements from which it will be constructed, in the form of some mathematical model characterized by sequences of input and output actions and also by the number and sequences of change of internal states of the device. In application to the consideration of such models there arose a series of theories--the theory of finite automata, the theory of abstract neural networks, the theory of logic networks, etc.-- many representations and concepts of which were found to be very useful for the development of the theory of relay devices.

All this required a significant reconsideration of both the assemblage of concepts and of the terms used in this theory. Here, in addition to the introduction of numerous terms which reflect the concepts of the forementioned stage of the abstract synthesis, it was necessary to generalize the previously existing concepts for the two-position contacting relay devices to the relay devices using contactless, multiposition, etc., elements.

This defined an essentially different approach to the construction of the system of concepts as a whole. First of all there arose the question of the basic term which defines the class of devices pertaining to the term relay. At the basis of the terminology of 1950 and 1953 there had been the concept of the contacting relay circuit as "an electrical circuit with relay action in which the change of the parameter is accomplished by means of the closing and opening of electrical contacts and in which electrical relays are present as the elements," and the concept of the contacting relay diagram as "a graphical representation of a relay circuit or system."

From the point of view of the contemporary development of relay technology, in particular in connection with the wide application of contactless relay elements, this definition is limited and does not embrace the entire diversity

of the relay devices which are considered in the modern theory of these devices. Therefore, as the basis of the proposed terminology list there have been established the concepts: of the relay element as "the minimal collection of components and connections between them which possesses the relay characteristic," and of the relay device as "a collection of mutually interacting elements in which the actions on any output can take only a finite number of fixed values."

The common specific property of such a class of devices is that they consist of a finite number of interconnected elements, each of which takes on a finite number of states. For the elements used to make up such devices various terms have been used, for example, "cells" (ref. 3), "abstract neurons" (ref. 4), "elements of the logic network" (ref. 5), "elementary components" (ref. 6) and so on. All these terms are related to the mathematical models in which various limitations are used, leading to an idealization of the real devices, or to the consideration of only definite subclasses of these devices. In numerous cases the models considered are of devices which consist only of elements of one class with respect to the functions they perform (for example, of elements with a given triggering threshold or of elements which perform instantaneous logic transformations, and also of delay elements), or which change their state only at instants of time having integral values, and so on. In other cases the considered models of the devices have limitations in the nature or the number of the connections between elements, etc.

Actual relay devices make extensive use of the most varied elements. Therefore, for the term which characterizes these elements it is not advisable to use any word which reflects the above-mentioned limitations.

With respect to real devices it is also inadvisable to use numerous terms used in the literature which relate to the devices under consideration as a whole, such, for example, as: "finite automat" (refs. 3, 6. 8), "digital automat" (ref. 7), "sequential machine" (ref. 8), "logic network" (ref 6), and so on, since they relate basically to the mathematical models of the class of devices in question. In addition, these terms are not very good choices insofar as the connotation value of the root terms appearing in them.

Thus, for example, in the terms "finite automat" and "digital automat" there appears the root term "automat." This term in the generally accepted connotation refers, as a rule, to devices operating without the direct participation of man (refs. 9, 10, 11), while in the class of devices in question in numerous cases human participation during functioning of the device is mandatory (telemechanical relay devices, relay devices used in communication, etc.).

The term "sequential machine" does not reflect the entire gamut of the relay devices since it relates only to the multicyclic devices in which there is provided a definite sequence of change of their states as a function of time. The root term "machine," although it has gained a broadened connotation recently ("computing machine," "logic machine," "controlling machine"), basically, however, refers to plants which perform the processing of materials or the transformation of energy.

The basic terms "relay element" and "relay device" adopted in the present terminology list are broader and more accurately reflect the entire gamut of

the existing relay devices and the elements used therein. They also have a definite advantage associated with the terms that are widely used in practice: "relay," "relay equipment," "relay action," and so on. Relay devices are frequently used as control devices in the current technology of automatic control. In this sense the root term "device" corresponds to the basic definitions relating to the automatic control devices and the automatic systems which have been accepted in the terminology of the basic concepts of automation (ref. 9).

The basic apparatus of the theory of relay devices is mathematical logic. In order not to burden the terminology list with the well-known definitions of mathematical terms, the latter are presented in a special appendix.

The large volume of existing terms encountered in the literature on the theory of relay devices has forced the authors of the present draft of the terminology list to limit themselves to the inclusion in this list of only those terms relating to the basic concepts, eliminating numerous secondary terms which are characteristic of individual classes of relay devices or which are utilized in various particular methods of synthesis and analysis of these devices.

Definite difficulties in the development of the terminology list arose in connection with the necessity for the generalization of numerous basic terms and definitions to the contacting and contactless devices (including nonelectrical) constructed using elements having significantly different structural properties and parameters. In order to overcome these difficulties there were introduced the concepts of the "conducting"and "nonconducting" states of the circuits of the structure of the relay devices, which are a generalization of the concepts of the "closed" and "open" states widely accepted in application to the contacting circuits. The concept of the "state" of a circuit is defined in terms of fixed values (with respect to the relay characteristic) of conductivity or other parameter, which makes it possible to relate this concept to both the contacting and contactless circuits and elements.

Certain difficulties also arose in the development of the generalized terms relating to the two-valued and multivalued relay elements.

The characteristics of the multivalued relay elements are reflected in the proposed draft of the terminology list by means of the introduction of the term "multiposition relay element" and by the indication of the specific properties of these elements in the notes to the corresponding definitions concerned with the states of the elements, circuits, relay devices as a whole, etc.

An essential difference is drawn in the terminology list between the structural and functional properties of the relay devices and the conditions of their operation.

All the terms relating to the structural properties of the relay devices are defined from the representations of an actual existing relay device in which the connections, circuit components and so on are actual existing objects. The terms relating to the functional properties of the relay devices are defined on the basis of the representation of the device in the form of a model whose elements are the links or blocks corresponding to some elementary function or to a structurally defined portion of a device which performs a definite, not

necessarily elementary, function. At the basis of the definitions of the majority of these terms there are established the concepts of the mathematical functions expressing the relationship between the states (or sequences of states) of the inputs and outputs, describing the transitions of the device from one state to another, and so on. All these definitions can refer both to an actual existing relay device having a definite structure and to some mathematical model of the device to which there might correspond various structures.

In contrast to this, the terms and definitions relating to the synthesis of the relay devices originate from the concepts of the functions which the device must perform and on the basis of which it is created from the beginning in the form of a mathematical model and then in the form of a control structure.

For convenience of use the terms and definitions are divided into groups relating to:

(1) relay elements;

(2) the general characteristics of relay devices;

(3) the structure of the relay device;

(4) its functional properties, and

(5) the analysis and synthesis of relay devices.

This division, naturally, is somewhat arbitrary.

The initial draft of the terminology list was compiled by Doctor of Technical Sciences, M. A. Gavrilov. It was reviewed and revised by a commission of the committee on technical terminology of the USSR National Committee on Automatic Control. The composition of the commission was as follows: Doctor of Technical Sciences, M. A. Gavrilov (chairman), Doctor of Technical Sciences, V. N. Roginskiy, Candidate of Technical Sciences, V. G. Lazarev, Candidate of Technical Sciences, P. P. Parkhomenko, Candidate of Physico-Mathematical Sciences, V. I. Shestakov (took part in the review and revision of part of the terms) and O. P. Kuznetsov, Junior Research Assistant.

The draft is being published for discussion and to obtain comments from interested organizations and from individual specialists, after which the commission will prepare the final text of the terminology list with consideration for the comments received.

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TERMINOLOGY OF THE THEORY OF RELAY DEVICES

1. Terms Relating to Relay Elements

1.1. Relay characteristic. The characteristic expressed by a function which with continuous variation of the argument (or arguments) takes two or several fixed values.

1.2. Relay element. The minimal collection of components and connections between them which has a relay characteristic.

Note 1. The relay characteristic may be organically inherent to the element or may be obtained artificially, for example by means of the choice of a suitable regime of operation of the element.

Note 2. Normally the argument of the function which expresses the relay characteristic of the element is the input action (see 1.6) while the values of the function are the internal states or the output actions.

1.3. Two-position relay element. A relay element whose characteristic is expressed by a function which takes two fixed values.

Note: The values of the function in this case are normally taken equal to 0 and 1.

1.4. Multiposition relay element. A relay element whose characteristic is expressed by a function which takes several fixed values.

Note: In the case of an n-position element the values of the function are normally taken equal to the numbers of the natural series from 0 to n-1.

1.5. Terminals of a relay element. The portions of a relay element through which there are applied to it actions from outside and through which it accomplishes transmission of an action to the outside.

Note: For definitions of actions and their classification see Basic Concepts of Automation (Osnovnyye ponyatiya avtomatiki) (IFAC 1960).

1.6. Input of a relay element. The terminal of a relay element through which an action from outside is applied to it.

Note: The action received by the relay element from the outside is termed the input action.

1.7. Output of a relay element. The terminal of a relay element through which it transmits an action to the outside.

Note: The action transmitted by a relay element to the outside is termed the output action.

1.8. Separative inputs of a relay element. The inputs of a relay element between which the transfer of action is not possible.

1.9. Separative outputs of a relay element. The outputs of a relay element between which the transfer of action is not possible.

1.10. Reactive organ of a relay element. The portion of a relay element which reacts to a specified change of the input actions.

1.11. Actuating organ of a relay element. The portion of a relay element which develops a specified output action.

1.12. Contact relay element. A relay element in which the actuating element is an electrical contacting device.

1.13. Contactless relay element. A relay element in which the actuating organ does not have electrical contacting devices.

Note: In the contactless relay elements the reactive and the actuating organs in many cases cannot be physically separated.

1.14. State of the input (inputs) of a relay element. One of the possible selected values (combinations of selected values) of actions on the input (each of the inputs) of a relay element at one instant of time.

1.15. State of the output (outputs) of a relay element. One of the possible selected values (combinations of selected values) of actions on the output (each of the outputs) of a relay element at one instant of time.

1.16. Internal state of a relay element. One of a finite number of states of all the components and connections of a relay element (except the inputs and outputs).

1.17. Total state of a relay element (state of a relay element). Aggregate of the state of the inputs and of the internal state of a relay element at one instant of time.

1.18. Stable state of a relay element. State of a relay element from which it can be disturbed only by a change of state of the input.

1.19. Unstable state of a relay element. State of a relay element whose change does not require a change of the input state.

1.20. Reaction of a relay element. Change of the internal state of an element.

Note: Sometimes, differentiation is made of the different forms of reaction, for example in the two-position elements we differentiate the energizing (tripping) of the relay element and the deenergizing (release) of the relay element.

1.21. Delay of a relay element (delay). The interval of time between the instant when the action on the input of the relay element attains the value corresponding to a new value of the output action on the relay characteristic and the instant of the appearance of this value on the output of the relay element.

Note: There exist relay elements in which the delay is strictly constant and relay elements in which its value depends on the parameters of the input actions and on other factors.

1.22. Essential delay. A delay whose magnitude must be considered in the treatment of the functions of the given element.

Note: A relay element whose primary function is the realization of an essential delay can be termed a relay delay element.

1.23. Inessential delay. A delay whose magnitude can be ignored in the consideration of the functions performed by the given element.

Note: The concepts of the essential and the inessential delay are relative and are determined by the purpose of the element and the conditions of its interaction with other elements.

1.24. Delay of reaction of a relay element. The interval of time between the instant when the action on the input of the relay element attains the value corresponding to a new internal state on the relay characteristic and the instant of the appearance of this state.

1.25. Relay element without retention of the internal state. A relay element in which the internal state is uniquely determined by the state of the inputs.

1.26. Relay element with retention of the internal state (relay memory element). A relay element in which the internal state is determined by the state of the inputs and by the preceding internal state.

Note: The term "storage element" can also be used.

1.27. Relay element with static input. Relay element which reacts to input actions whose duration exceeds the reaction delay time of this element to the given action.

1.28. Relay element with static output. Relay element whose output action uniquely corresponds to the state of the element and does not change if this state is retained.

1.29. Relay element with pulsed input. Relay element which reacts to input actions whose duration is less than the reaction delay of this element to the given action.

1.30. Relay element with pulsed output. Relay element whose output action uniquely corresponds to the change of state of the element and occurs in a definite period of time.

1.31. Relay element which reacts to switching (relay switch element). Relay element which reacts only to definite changes (switching) of the input actions.

1.32. Functional properties of a relay element. The relation between the state (sequence of states) of the inputs and the state (sequence of states) of the outputs.

Note: The functional properties of a relay element can be described by tables, logic functions (systems of functions), etc., which give the dependence of the output states on the input states, internal states, and delays. Sometimes these relations may be probabilistic.

2.   Terms Relating to the General Characteristic of a Relay Device

2.1. Relay device. A collection of interacting elements in which the actions on any output can take only a finite number of fixed values.

Note 1. The inputs of the relay device, by analogy with the relay element, are those terminals on which actions from outside are applied, while the outputs are the terminals through which the relay device transmits an action to the outside.

Note 2. Devices in which a portion of the outputs have a relay characteristic while another portion do not have this characteristic should be termed mixed devices.

Note 3. By analogy with the state of the inputs of the relay element, the state of the inputs of the relay device is defined as one of the possible combinations of selected values of the actions on each of the inputs of the relay device at one instant of time; the state of the outputs of the relay device is defined similarly.

Note 4. By analogy with the separative inputs and outputs of a relay element, the separative inputs or outputs of a relay device are the terms given to the inputs or outputs of a relay device between which the transfer of action is not possible.

Note 5. A finite number of fixed values of the output actions of a relay device can take place both as a result of the fact that there is at least one relay element between each input and output and as a result of the fact that on the inputs of the relay element there is applied only a preselected finite number of fixed values of the actions.

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2.2. Element of a relay device. A relay or other element appearing in the structure of a relay device.

2.3. Power supply element of a relay device. The element of a relay device which is the source of the energy necessary for the operation of the relay device.

Note 1. In many cases, in place of the power supply elements we consider inputs to which there are connected the power sources (power inputs) of the relay device.

Note 2. The power supply elements do not change their state during operation of the relay device.

2.4. Connecting element of a relay device. An element of the structure of a relay device which serves for permanent connection of the other elements with one another.

Note: The connecting elements in the relay device can be: connecting wires, disconnect plugs, connecting tubes (in pneumatic and hydraulic relay devices), etc. The connecting elements do not change their state during the operation of the relay device.

2.5. Limiting element of a relay device. The element of a relay device which limits the action within the relay device with respect to some parameter.

Note: The limiting elements in the relay device can be: various linear or nonlinear resistors, fuses, elements with one-way conductivity, etc. The limiting elements can change their state as a function of the magnitude or direction of the actions taking place in them.

2.6. Functional element of a relay device. An element of a relay device whose purpose is participation in the performance of the function realized by the relay device.

Note: Among the functional elements we can differentiate the sensing elements of the relay device whose purpose is the sensing of action from without, the actuating elements whose purpose is the transmission of the action from the relay device to the outside, and the intermediate (internal) elements whose purpose is the transmission of the action within the relay device.

2.7. Internal state of a relay device. One of the possible combinations of the states of the outputs of the delay elements and of the internal states of the storage elements of a relay device at one instant of time.

2.8. Total state of a relay device. The aggregate of the input states and the internal states of a relay device at one instant of time.

Note: We differentiate the abstract representation of the states (abstract states) in which each state is designated by an ordinal number or letter, and the structural representation of the states (structural states) in which the

state is designated by an n-digit number, each digit of which corresponds to the state of some element of the relay device.

2.9. Stable state of a relay device. The state of a relay device in which each of its elements is in a stable state.

2.10. Unstable state of a relay device. The state of a relay device in which at least one of its elements is in an unstable state.

3. Terms Relating to the Structure of a Relay Device

3.1. Structure of a relay device. The assembly of elements and connections, along which there proceed the interactions between the elements and also between the inputs and outputs, which form the relay device.

3.2. Structural diagram of a relay device. The symbolic graphical representation of a relay device which presents a biunique reflection of its structure.

3.3. Node of the structure of a relay device. A lead or a point of connection of several leads of the elements of a relay device.

Note: A node of the structure which coincides with a terminal of the structure can be termed an input or output node (pole) of the structure.

3.4. Component of the structure of a relay device. The reactive or actuating organ of a relay element or another element which is connected between two nodes of a relay device.

Note: Depending on the arbitrarily selected direction of passage of an action through the component, one of the nodes between which it is connected is termed the initial node and the other is termed the final node.

3.5. Parallel connection of components. A connection of the components in which all the initial nodes of the components are combined into a single initial node and all the final nodes of the components are combined into a single final node.

3.6. Series connection of components. The connection of two components in which the final node of one of the components is connected to the initial node of the other; the initial and final nodes of such a connection are the free initial node of one component and the free final node of the other, respectively.

3.7. Elementary circuit of a relay device. One or several sequentially connected components of the structure of a relay device, connected between two given nodes of a structure.

Note: The nodes between which the elementary circuit is connected can be termed the poles of the elementary circuit.

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3.8. Complex circuit of a relay device (circuit of a relay device). The aggregate of the elementary circuits between two given nodes of the structure.

Note 1. If one of the nodes of the circuit of a relay device is the input (output) node of the structure, then this circuit is termed the input (output) circuit. Otherwise the circuit is termed internal.

Note 2. A circuit of a relay device which connects the input node of the structure with its output node and does not contain the reactive organs of the relay elements is termed a through circuit.

3.9. Bridge component. A component of a complex circuit of a relay device which is simultaneously a part of some two of its elementary circuits such that each node of the component is the initial node in one of these circuits and is the final node in the other circuit.

3.10. State of a circuit of a relay device (state of a relay circuit). One of the values of conductivity or other parameter of a relay circuit corresponding to the relay characteristic defined by the combination of the states of the relay elements whose components participate in the given circuit.

Note 1. For two-valued states of the circuit we usually differentiate the conducting and nonconducting states (or for the contacting circuits the closed and open states). For the multivalued states of the circuit we usually separate the nonconducting state and differentiate several degrees of conductivity.

Note 2. In accordance with the specific nature of the relay circuits, in place of conductivity we also use the term structural conductivity of the relay circuit.

Note 3. By analogy with the state of the circuit of a relay device, we can talk of the state of a component of the structure.

3.11. Circuit of a relay device which is the inverse with respect to the given circuit (inverse circuit). A circuit (elementary or complex) of a relay device whose state is conducting for a nonconducting state of the given circuit and vice versa.

Note: With a number of values of conductivity of the relay circuit greater than two, the concept of the inverse circuit is defined in accordance with the definition of inversion in the system of multivalued logic used for the description of the given structure.

3.12. Relay two-terminal network. Structure of a relay device or a separable portion of it which has only two poles.

Note 1. The initial and final poles of the two-terminal network are defined by analogy with the definition of the initial and final nodes of a component of the structure of a relay device (see Note to 3.4).

Note 2. The parallel and series connection of two-terminal networks are defined by analogy with the definitions of similar connections of the components of the structure of a relay device (see 3.5 and 3.6).

Note 3. The state of a two-terminal network is defined by analogy with the definition of the states of the circuit of a relay device (see 3.10).

3.13. Relay network. The structure of a relay device or a separable portion of it which has more than two poles.

Note: The relay network in which there are separated p input and k output poles is termed a (p,k)-terminal network; when it is necessary to differentiate the p_1 initial nodes of the through circuits from the p_2 initial nodes of the input circuits we can make use of the notation of the form--$(p_1 + p_2, k)$-terminal network.

3.14. Section of a relay device. The aggregate of the components of the structure of a relay device whose nonconducting state brings into a nonconducting state all the elementary circuits between the input and output poles of the structure.

Note: A section which ceases to be a section when any of its components are removed is termed irredundant.

3.15. Parallel-series structure of a relay device (class Π structure). The structure of a relay device obtained by series and parallel connections of its components.

3.16. Bridge structure of a relay device (class H structure). The structure of a relay device containing a bridge component.

3.17. Structural tree. The structure of a (1,K)-network in which all the circuits between the input pole and any of the K output poles are elementary circuits.

3.18. Iterative structure. Structure of a relay device consisting of identical two-terminal networks or networks which are identically connected among themselves.

3.19. Plane (planar) structure. The structure of a relay device whose diagram can be represented on a plane without intersections of the lines representing the individual relay circuits appearing in the structure, including the power supply source circuits.

3.20. Nonplane (nonplanar) structure. The structure of a relay device whose diagram cannot be represented on a plane without intersections of the lines representing the individual relay circuits appearing in the structure, including the power supply source circuits.

4. Terms Relating to the Functional Properties of a Relay
   Device

   4.1. Functional properties of a relay device. The relationship which
exists in a relay device between the states (sequence of states) of the out-
puts and the states (sequences of states) of the inputs of the relay device.

   Note 1. By analogy with "Terminology of the Basic Concepts of Automation"
(IFAC 1960) in place of the indicated term we can also use the term "function
algorithm of a relay device."

   Note 2. In place of the term "functional properties of a relay device"
we can speak of "the function realized by a relay device."

   Note 3. The functional properties of a relay device can be described
analytically, graphically, or in the form of a table.

   4.2. Output function of a relay device. The functional properties of a
relay device defined with relation to a given output.

   4.3. Switching function of a relay device. The dependence of the internal
state of a relay device at the present moment on the preceding internal states
and on the state of the inputs at the present moment.

   Note: For relay devices which contain as sensing elements those with
pulsed input or which react to switching, the internal state may also depend
on the state of the inputs at preceding moments of time.

   4.4. Functional link of a relay device. An artificially separated
portion of a relay device corresponding to some elementary function.

   Note 1. A functional link may reflect, for example, an elementary logic
function (disjunction, conjunction, negation, etc.), an elementary delay func-
tion, an elementary memory function, etc.

   Note 2. The functional link may coincide with a functional element of
the relay device.

   Note 3. An arbitrarily separated point through which there is transmitted
an action corresponding to the argument of the function realized by the given
link should be termed an input of a functional link; an arbitrarily separated
point through which there is transmitted an action corresponding to the value
of the function realized by the given link should be termed an output of a
functional link. The inputs and outputs of the functional link can be termed
leads.

   4.5. Functional diagram of a relay device--is a symbolic graphical rep-
resentation of a relay device consisting of an aggregate of interconnected
functional links and uniquely reflecting the functional property of the relay
device.

Note 1. The functional diagram of a relay device can be represented as consisting of the logic portion including in itself the functional links reflecting the logic functions, and of the storage portion including in itself the functional links reflecting the elementary functions of delay and memory.

Note 2. In the construction of the functional diagram from the functional links it is normally considered that the latter possess directivity (from the inputs toward the outputs) and separability.

4.6. Functional block of a relay device. The actually existing constructionally expressed portion of the relay device which accomplishes a definite function.

4.7. Block diagram of a relay device. The symbolic graphical representation of a relay device consisting of a collection of interacting functional blocks.

4.8. Circuit of a functional diagram. The transmission path of the actions in the functional diagram of a relay device.

4.9. Node of a functional diagram. Terminal or point of connection of leads of the functional links.

Note 1. By analogy with the concept of "output function" we can speak of a "node function" if the given node is taken as an output.

Note 2. By analogy with the concept of node and circuit of the functional diagram we can use the concept of "node of a block diagram" and "circuit of a block diagram."

4.10. Switching table. A table which describes the switching function and output functions of a relay device using an abstract representation of the states.

Note 1. Frequently a separate table is constructed for the output functions and in this case the table should be termed the output table.

Note 2. Various forms of tables are used:

(a) a square switching table (switching matrix whose rows and columns correspond to the internal states of the relay device while the elements of the matrix are the states of the inputs or the changes of the states of the inputs which transfer the relay device from one state to another);

(b) a rectangular switching table whose columns correspond to the states of the inputs, the rows correspond to the states of the relay device at the present moment, while in the cells of the table there are written the corresponding internal states in the succeeding moment.

4.11. Switching graph (switching diagram). A graph describing the switching function of the relay device.

Note 1. Frequently, in the switching graph there are indicated the states of the outputs corresponding to the states or to the changes of the states of the relay device.

Note 2. In many cases an individual switching graph is constructed for each state of the inputs of the relay device.

4.12. Table of states. A switching table (or only a table of the outputs) using the structural representation of the states.

4.13. Cycle of operation of a relay device. Interval of time between two successive changes of the total state of a relay device.

4.14. Table of inclusions. A table whose columns correspond to the numbers of cycles of operation of a relay device while the rows correspond to the states of the inputs of the internal elements and outputs of the relay device.

4.15. Single-cycle relay device. A relay device in which the state of its outputs at every given moment of time is uniquely determined by the state of the inputs at that same instant of time.

Note 1. In the single-cycle relay devices with pulsed outputs and static inputs, the state of the outputs is uniquely determined by the change of the state of the inputs.

Note 2. The single-cycle relay device does not contain essential delays or memory elements.

4.16. Multicycle relay device. A relay device in which the state of its outputs at a given instant of time is determined by the state of the inputs of the device, and also by the state of the outputs of the delay elements and the memory elements at that same instant of time.

Note: In the multicycle relay devices with pulsed outputs, static inputs, and static outputs of the delay elements and of the memory elements, the state of the outputs is uniquely determined by the change of the state of the inputs of the device and the change of the state of the outputs of the memory elements and the delay elements.

4.17. Synchronous relay device. A relay device in which the states of the inputs are sensed only at the instants of the application of an action on a specially separated input.

Note: The specially separated input of the synchronous device is normally termed the synchronizing input, while the other inputs are termed the informational inputs.

4.18. Asynchronous relay device. A relay device in which there is no synchronizing input.

4.19. Autonomous regime of operation of a relay device. Functioning of a multicyclic relay device with a constant state of the inputs.

Note: A relay device which has only an autonomous regime of operation is termed autonomous.

4.20. Switching process in a relay device. The phenomenon taking place in a relay device during the transfer of the device from one given state into the following given state.

4.21. Competition of relay elements. A switching process during which more than one element is simultaneously in an unstable state.

4.22. Competition of relay circuits. A switching process during which different circuits do not change their state strictly simultaneously.

4.23. Permissible competitions. Competitions of relay elements or circuits which cannot cause degradation of the functional properties (of the function algorithm) of the relay device.

4.24. Forbidden competitions. Competitions of relay elements or circuits which can lead to degradation of the functional properties (of the function algorithm) of the relay device.

Note: With respect to the forbidden competitions of the relay circuits, we differentiate forbidden competitions of the first kind which can be eliminated by means of definite changes of the logic portion of the relay device, and the forbidden competitions of the second kind whose elimination can be accomplished only by the introduction of additional delays.

5. Terms Relating to the Analysis and Synthesis of Relay Devices

5.1. Conditions of operation of a relay device. The required variation of the states (sequence of states) of the outputs as a function of the states (sequence of states) of the inputs of the relay device, expressed literally or by some formalized language.

Note 1. The functional properties of the realized relay device must correspond to its conditions of operation.

Note 2. In the formulation of the conditions of operation, we normally assume that one or several of the initial states of the device are known.

Note 3. In the formulation of the conditions of operation, indications may be made of the various limitations affecting the synthesis of the structure, namely: the structural properties of the elements, type of the structure itself, tolerances on the parametric relationships, requirements on reliability, etc.

5.2. Contradictory conditions of operation of a relay device. Conditions of operation in which to the same sequence of states of the inputs for the same initial state there correspond different sequences of the states of the outputs.

Note: The contradictory conditions of operation are not realizable. i.e., it is not possible to construct a relay device whose functional properties would correspond to these conditions of operation.

5.3. Inoperative state of a relay device with respect to a given output. The state of a relay device in which the given output function takes the value 0.

Note: With a zero value of the output function the output circuits of the given output are in a nonconducting state.

5.4. Operative state of a relay device with respect to a given output. The state of a relay device in which the given output function takes a value differing from zero.

Note: With a nonzero value of the output function at least one of the output circuits of the given output is in the conducting state.

5.5. Indifferent state of a relay device with respect to a given output. A state of a relay device which, with respect to conditions of operation, can be either operative or inoperative with respect to a given output.

5.6. Unused state of a relay device. A state of a relay device which, in conformance with the conditions of operation, cannot take place.

Note: The indifferent and unused states are frequently termed the conditional states. The values of the output function are indeterminate for the conditional states.

5.7. Unused sequence of states of the inputs. A sequence of states of the inputs which, in accordance with the conditions of operation, cannot take place.

5.8. Complete conditions of operation of a relay device. Conditions of operation from which for any sequence of inputs we can either determine that the sequence is unused or can determine the corresponding sequence of states of the outputs.

5.9. Synthesis of a relay device. Determination of the structure of a relay device from the conditions of operation specified for it.

Note: It is customary to differentiate three stages of the synthesis of relay devices:

(a) abstract synthesis, which does not take account of the properties of the actual relay elements from which the device is constructed and terminates with the writing of the transfer function (in the form of a transfer table, a transfer graph, a transfer matrix, etc.);

(b) the synthesis of the state table, which terminates in the construction of a state table (truth table) in accordance with the given transfer table;

(c) structural synthesis, which terminates with the construction of the structure of the relay device in accordance with the given state table. If the structural synthesis is terminated with the construction of a functional diagram then it should be termed logical synthesis.

5.10. Analysis of a relay device. Determination of the functional properties of a relay device from its given structure.

Note 1. In many cases, to obtain unambiguous results of the analysis it is necessary to know the parametric relationships present in the structure (ratio of delays, ratio of the conductivities of the various circuits, etc.), the initial state of the device, etc.

Note 2. By analogy with the synthesis steps we can differentiate three stages of analysis:

(a) structural analysis--the construction of a state table corresponding to the given structure of a relay device;

(b) analysis of the state tables--the construction of the transfer function corresponding to the given state table;

(c) abstract analysis--the determination of the functional properties of a relay device corresponding to a given transfer function.

5.11. Equivalent relay devices are devices which realize the same conditions of operation.

5.12. Equivalent transformations are transformations of the forms of the representations of the functional properties or of the structure of a relay device as a result of which there is obtained a form of representation of the device which is equivalent to the original.

Note: Depending on the form of the representation, we can speak of equivalent transformations of transform tables (graphs), functional diagrams, structural formulas (diagrams), etc.

5.13. Minimization. Equivalent transformations directed to the reduction of the value of some criterion of the complexity of a relay device.

Note: Depending on the complexity criterion selected, we can speak of minimization of the number of states of a relay device, the number of relay elements, etc.

5.14. Disposition (coding) of states. Correlation of one or several structural states to each abstract state.

5.15. Compatible states--two abstract states of a relay device which can be exchanged without degradation of its conditions of operation.

Note: Compatible states are characterized by the fact that if they are taken to be the initial states, regardless of what input sequence is used of

those that are possible in accordance with the conditions of operation, they will not give different output sequences.

5.16. Equivalent states--are compatible abstract states of a relay device whose set of unused input sequences coincide.

5.17. Irredundant form of representation of a relay device is the form of representation of a relay device whose further minimization leads to forms of representation of devices which are not equivalent to the original.

Note: Depending on the form of representation of the relay device considered, we can speak of irredundant transfer table, irredundant functional diagram, irredundant structural diagram, irredundant form of Boolean function, etc.

5.18. Minimal form of representation of a relay device. Irredundant form of representation of a relay device for which the value of the selected criterion of complexity is minimal.

APPENDIX TO TERMINOLOGY OF THE THEORY OF RELAY DEVICES

Some Terms of Mathematical Logic

1. Logical k-valued function (function of the class P_k)--a function, taking k values, whose arguments also take on k values.

Note 1. Every k-valued logical function of n variables can be given by a table in which there are indicated the values of the function for each of the k possible combinations of values of the arguments.

Note 2. The two-valued logic functions are frequently termed Boolean functions (functions of the class P_2) or functions of logic algebra.

2. Some basic logic functions and their notations:

Negation (NOT function, inversion) $\qquad$ — ,'

Disjunction (nonexclusive OR, logical summation) $\qquad$ $\cup$, +

Conjunction (AND function, logical multiplication) $\qquad$ $\cap$, $\cdot$

Implication $\qquad$ $\rightarrow$, $\supset$

Equivalence $\qquad$ $\leftrightarrow$, $\equiv$

Nonequivalence (exclusive OR, modulo 2 summation) $\qquad$ $\oplus$

Sheffer's function (Sheffer's stroke) $\qquad$ |

Webb's function (Pierce's arrow) $\qquad$ $\downarrow$

Constant 0

Constant 1

Table for negation

X	$\bar{X}$
0	1
1	0

TABLE FOR REMAINING FUNCTION

$x=y$	$x+y$	xy	$x \rightarrow y$	$x-y$	$x \oplus y$	$x \mid y$	$x \downarrow y$	0	1
0 0	0	0	1	1	0	1	1	0	1
0 1	1	0	1	0	1	1	0	0	1
1 0	1	0	0	0	1	1	0	0	1
1 1	1	1	1	1	0	0	0	0	1

3. The functionally complete system of k-valued functions (base)--a system of k-valued functions possessing the property that any k-valued function of any number of variables can be represented in the form of a superposition of functions of this system.

4. Representation of a function in a given base (formula in a given base). Writing a function in the form of a superposition of functions of a given base.

Note 1. One and the same function in one and the same base can have several (and even infinitely many) formulas representing it. The formulas are termed equivalent if they represent one and the same function.

Note 2. Examples of bases for Boolean functions:

1) conjunction, negation,

2) disjunction, negation,

3) conjunction, disjunction, negation,

4) Sheffer's stroke,

5) Webb's function,

6) conjunction, modulo 2 addition, constant 1.

Note 3. The following concepts relate to the representation of the Boolean functions in the base 3).

5. Disjunctive normal form of a function--the representation of a function in the form of the sum (disjunction) of the products of the variables.

6. Conjunctive normal form of a function--the representation of the function in the form of the product (conjunction) of the sums of the variables.

7. The function "constant 1," considered as a function of n variables, has the following representation in the base 3)

$$1 = x_1 x_2 \ldots x_n + x_1 x_2 \ldots \overline{x}_n + \ldots + \overline{x}_1 \ldots \overline{x}_n.$$

Each term of this sum is the product of all n variables, where each variable enters into this product one time--either with or without negation. These products of the variables are termed "constituents of unity." All 2^n different possible constituents of unity enter into the representation of the function 1.

8. The complete disjunctive normal form of the Boolean function--is the representation of the Boolean function in the form of the sum of the constituents of unity.

9. The function "constant 0," considered as a function of n variables, has the following representation in the base 3)

$$0 = (x_1 + \ldots + x_n)(x_1 + \ldots + \overline{x}_n) \ldots (\overline{x}_1 + \ldots + \overline{x}_n).$$

Each co-factor of this product is the sum of all the variables, where each variable enters into it one time--either with or without negation.

These sums of the variables are termed "constituents of zero."

10. The complete conjunctive normal form of the Boolean function--is the representation of the Boolean function in the form of the sum of the constituents of zero.

11. The implicant of the function $f(x_1, \ldots, x_n)$--is the product of certain of the variables $x_1, \ldots x_n$ (possibly with negation) which do not contain simultaneously the variable and its negative, such that the formula $p \rightarrow f(x_1, \ldots, x_n) = 1$ is valid for any values of $x_1, \ldots, x_n$.

12. The simple implicant--is an implicant which will cease to be an implicant when any of its co-factors is eliminated.

Note: Each Boolean function has a finite number of simple implicants. The sum of all the simple implicants of a function is equivalent to this function and, consequently, is one of its normal forms. Sometimes it is called the abbreviated normal form.

13. Minimum normal form (irredundant normal form) of the Boolean function--is the sum of certain simple implicants of the function which is a representation of this function but ceases to be a representation when any of its terms are eliminated.

14. Incompletely determined Boolean function--a function whose value is not defined for certain sets of values of its variables.

15. The complete determination of the Boolean function $f(x_1, \ldots x_n)$--is the completely determined Boolean function $g(x_1, \ldots, x_n)$ such that for all

sets of the variables $\bar{x}_1, \ldots, \bar{x}_n$ on which f is determinate

$$f(\bar{x}_1, \ldots, \bar{x}_n) = g(\bar{x}_1, \ldots, \bar{x}_n)$$

Note: If the Boolean function f is not determinate on k of the sets, then 2^k different complete determinations of f are possible.

16. The minimal term of the incompletely determined Boolean function $f(x_1, \ldots, x_n)$--is the product of certain of the variables $x_1, \ldots, x_n$ (possibly with negation) which do not contain simultaneously the variable and its negation and which is the simple implicant of at least one of the complete determinations of f.

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